# Open-Mic Session

# 5 minutes, *including discussion*

# Jets and Heavy Flavor at EIC as an important part of its Physics Program

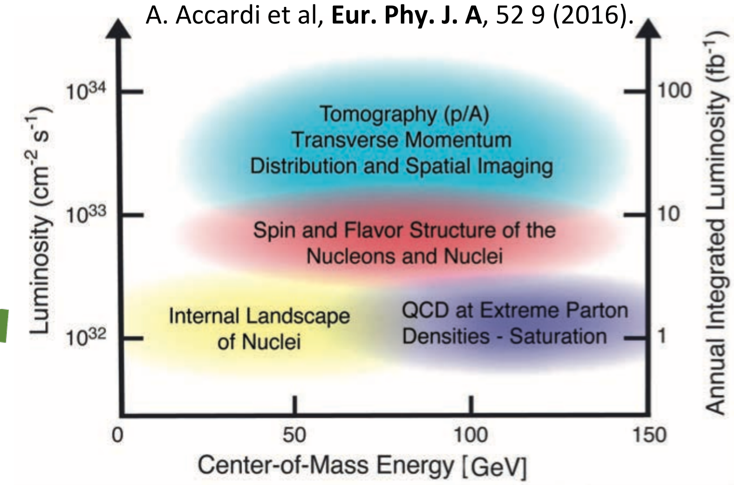
Xuan Li, Los Alamos National Laboratory

# Jets and heavy flavor at EIC as an important part of its physics program

## - new developments/progress at LANL

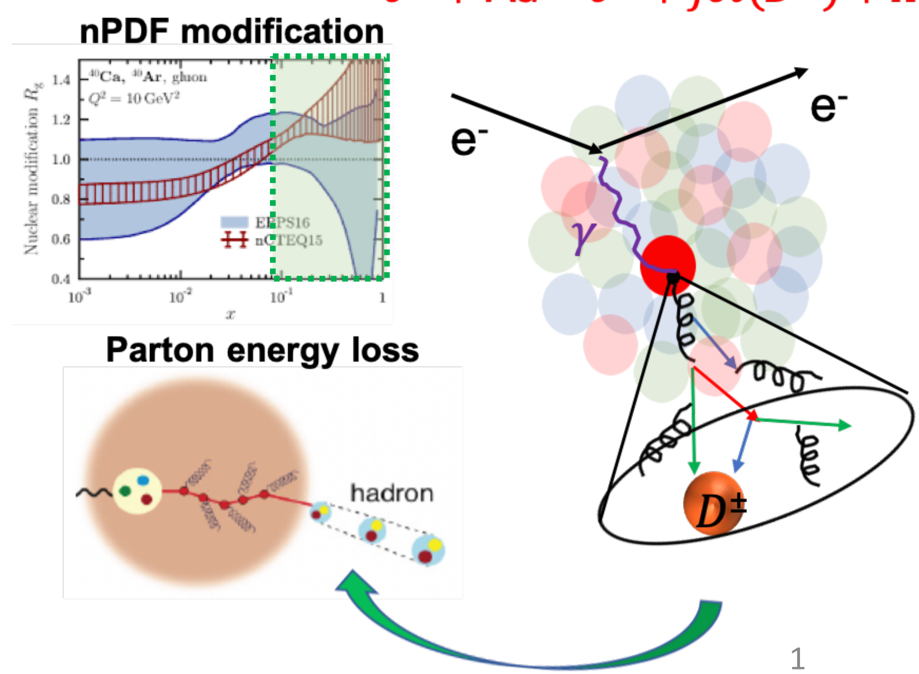
- EIC can help solve different fundamental physics problems in a wide x and $Q^2$ kinematic region, including providing a clean environment to study the flavor dependent energy loss and hadronization in nuclear medium. Forward silicon tracking is essential to realize such measurements.

A. Accardi et al, **Eur. Phy. J. A**, 52 9 (2016).




- LANL experimental group worked on silicon vertex and tracking detectors for 20 years and the theoretical group developed the energy loss mechanisms and leads several other QCD topics.

$$e^- + \mathrm{Au} \rightarrow e^- + jet(D^{\pm}) + X$$

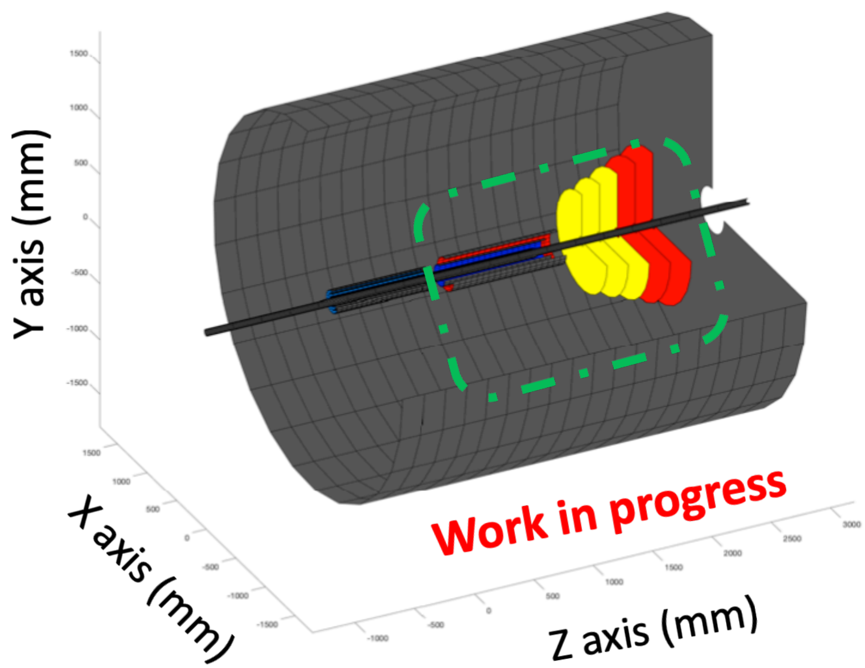


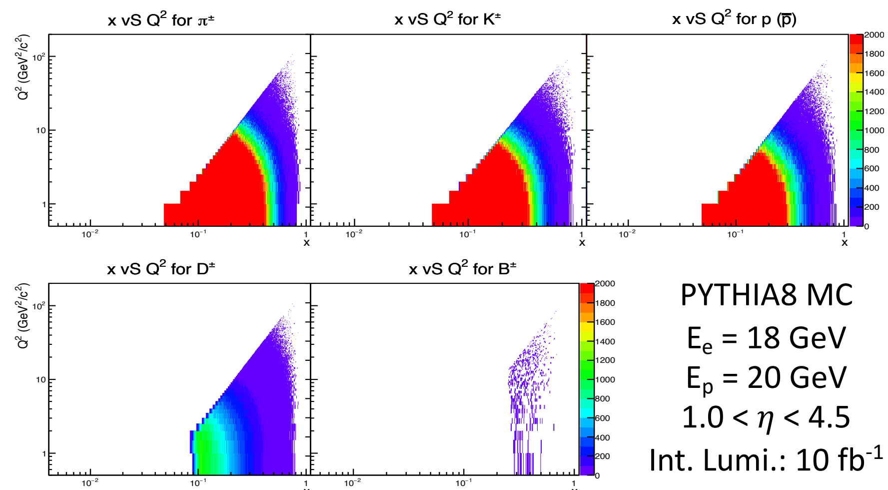

- A new 3-year LDRD project funded by LANL with **PI:** Ivan Vitev, **Co-PI:** Xuan Li and **14 staffs and postdocs** just starts to **develop a new heavy flavor and jet program for the future EIC and carry out relevant detector R&D.**

# EIC detector requirements for heavy flavor (jet) studies

- To measure heavy flavor products, jets and their correlations in the hadron/nuclei going (forward) direction at the EIC, we proposed to build the Forward Silicon Tracking (FST) detector for the future EIC.
- Initial detector design and performance evaluation in fast simulation. Will carry out studies in the EIC official software.

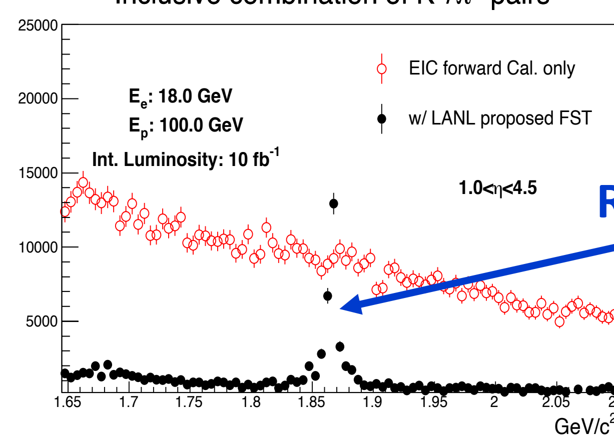
FST: $1.0 < \eta < 4.5$




PYTHIA8 MC
$E_e$ = 18 GeV
$E_p$ = 20 GeV
$1.0 < \eta < 4.5$
Int. Lumi.: 10 $fb^{-1}$

Inclusive combination of $K^{\pm}/\pi^{\pm}$ pairs



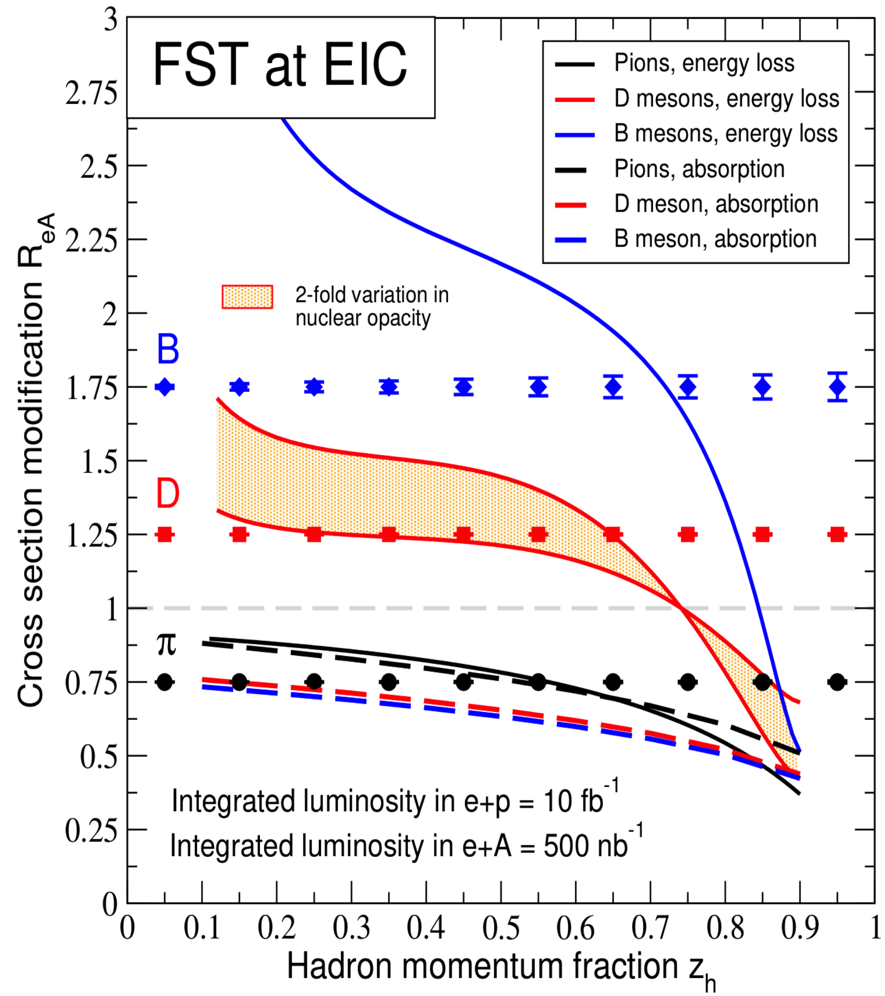

Reconstructed $D^0$ meson

- Detector R&D underway.

# Fundamental outputs of heavy flavor and jets physics program at EIC

- Competing models of nuclear modification in DIS reactions with nuclei (e.g HERMES data). Differentiation not possible with light hadrons.
  - Hadronization inside nuclear matter (dashed lines).
  - Energy loss of partons, hadronization outside the nuclear matter (solid lines).
- Heavy flavor mesons have very different fragmentation functions and formation times
  - Easy to discriminate between larger suppression for D/B mesons (in-medium hadronization) and strong/intermediate z enhancement (E-loss).
  - Enhanced sensitivity to the transport properties of nuclei.

Projection in $\sqrt{s}$ = 69 GeV e+Au collisions




**We look forward to integrate into the physics/detector working group's efforts!**

# MAPS sensor/detector efforts at CERN with possible applications to EIC

Leo Greiner, Lawrence Berkeley Natl. Lab.

## Kickoff meeting held at CERN on December 4, 2019 for “ALICE ITS Upgrade in LS3”

https://indico.cern.ch/event/860914/

The most relevant efforts in this Letter of Intent (endorsed by the LHCC in September 2019) include:

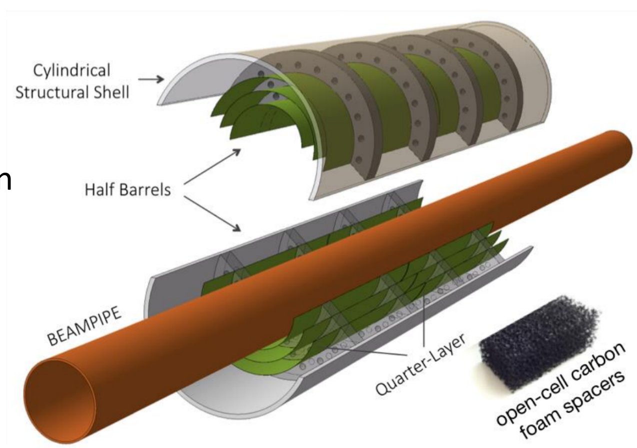
- Silicon R&D for next generation MAPS sensor (with significant improvements)

coupled with

- R&D into extremely low X/X0 cylindrical vertex detection with “bent” silicon

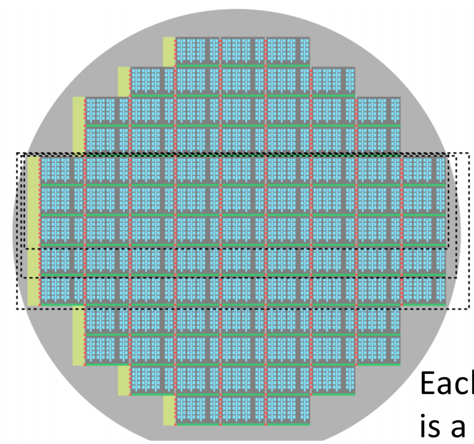
*Much of this has already been presented by my colleague Vito Manzari at 2019 EIC User Group Meeting, 22-26 July 2019 Paris*

“bent” silicon Detector concept




X/X0 ~ 0.05%

“stitched” silicon



Each layer half barrel is a single stitched sensor

From Electron-Ion Collider Detector Requirements and R&D Handbook Version 1.1 p.30 4.1.1.2 Vertex/silicon tracker:

"With respect to ALPIDE, the EIC would certainly benefit in improvements in the integration time as well as in a further reduction of the energy consumption and material budget going towards 0.1-0.2% radiation length per layer. Timing-wise the ultimate goal of this technology would be to time stamp the bunch crossings where the primary interaction occurred."

Sensor Specifications

| **Parameter** | **ALPIDE (existing)** | **Wafer-scale sensor (this proposal)** |
|---|---|---|
| Technology node | 180 nm | 65 nm |
| Silicon thickness | 50 µm | 20-40 µm |
| Pixel size | 27 x 29 µm | O(10 x 10 µm) |
| Chip dimensions | 1.5 x 3.0 cm | scalable up to 28 x 10 cm |
| Front-end pulse duration | ~ 5 µs | ~ 200 ns |
| Time resolution | ~ 1 µs | < 100 ns (option: <10ns) |
| Max particle fluence | 100 MHz/cm$^2$ | 100 MHz/cm$^2$ |
| Max particle readout rate | 10 MHz/cm$^2$ | 100 MHz/cm$^2$ |
| Power Consumption | 40 mW/cm$^2$ | < 20 mW/cm$^2$ (pixel matrix) |
| Detection efficiency | > 99% | > 99% |
| Fake hit rate | < $10^{-7}$ event/pixel | < $10^{-7}$ event/pixel |
| NIEL radiation tolerance | ~3 x $10^{13}$ 1 MeV $n_{eq}$/cm$^2$ | $10^{14}$ 1 MeV $n_{eq}$/cm$^2$ |
| TID radiation tolerance | 3 MRad | 10 MRad |

# Comments

- This approved and supported research and development project contains many elements that can have application in an EIC detector set.
- The overlap between the sensor development goals and EIC requirements is significant.
- The timeframe (ALICE ITS 3 installation during CERN LS3) seems to be a reasonable match.
- CERN and collaborators will invest significant resources in this project => high likelihood of success.

- LBNL-RNC has joined this effort.
- In addition to the ALICE work package efforts that we are joining, we intend to also invest in the development of making stitched sensors into low X/X0 discs.
- We have spoken to others about these efforts (ITS3 silicon/detector and discs) and there is some interest in forming a group effort for applying these developments for EIC.

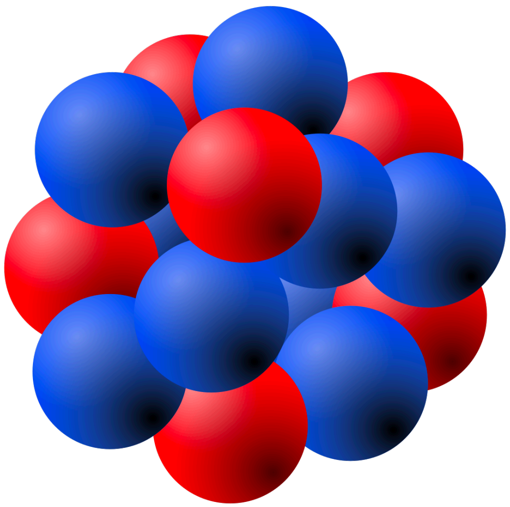
- Any questions or interest, please talk to me.

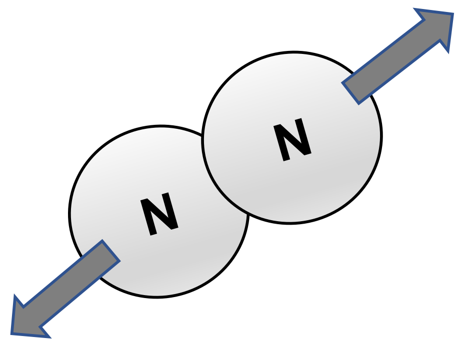
# Entanglement and Correlations at short distances at an EIC

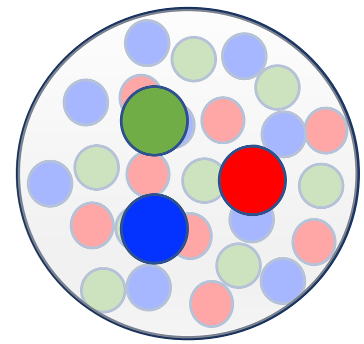
Kong Tu, Brookhaven National Lab.

# Standing problem in QCD and modern physics

Correlated nucleon pairs?





Bounded nucleus?

Confinement?

## Can QCD rule them all?

- Short distance dynamics? Gluons?
- Mystery of nucleon modification

**connected?**

- How to “crack” *confinement?*
- Partons are entangled?

# Possible measurements and impact on detectors

- Short-Range Correlations (SRC) in light and/or heavy nuclei for ***extreme configuration***, e.g., J/psi production off deuterium.
  **(*Miller, Sievert,* and *Venugopalan* (2016) )**
- Spectator tagging physics
  ***(C.Weiss, M. Strikman)***
- ***…***

Very forward instrumentations are needed.
(protons/neutrons, acceptance, resolution)

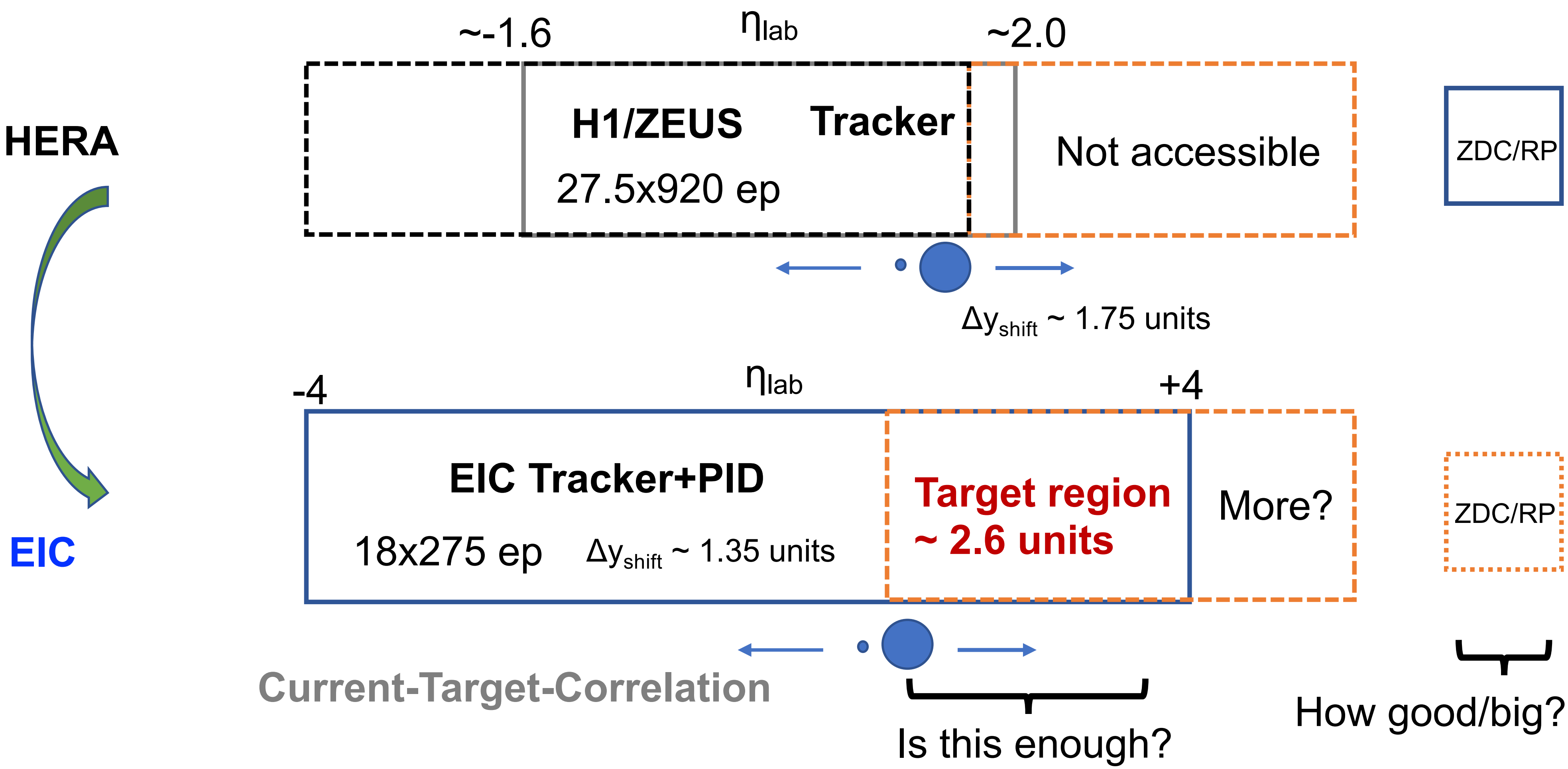
Initial studies have been done, but not enough.
Will need detail NUMBERS.

- Entanglement in proton and nucleus via measurements of multiplicity distributions in target fragmentation.
  **(D.Kharzeev, E. Levin, Z.Tu, T.Ullrich)**
- Entanglement via spin correlation. Test of Bell-equality in high energy collisions.
  **(Z.Tu, D.Kharzeev, T.Ullrich in preparation)**

Access to Target fragmentation
(tracking, PID?)

How forward is needed ?
Still under study.

# Possible measurements and impact on detectors




**Yellow Report** should address these **requirements quantitatively**

# Prospects for Di-hadron and Lambda Measurements

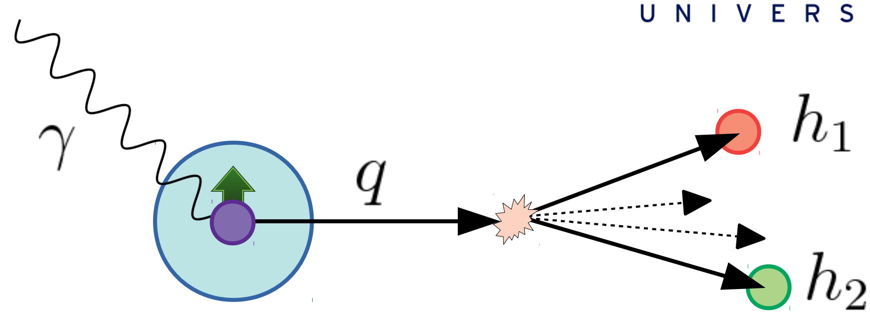
Chris Dilks, Duke University

# Dihadrons: Probing Spin-Orbit Correlations in Hadronization

Duke UNIVERSITY

## Unpolarized SIDIS:

- **Cahn Effect**: quark transverse momentum leads to azimuthal modulations of SIDIS cross section
- **Boer-Mulders Effect:** Non-collinear quarks in an unpolarized proton can have transverse polarization




- **Dihadrons can help decouple BM from Cahn**
  - Single-hadron SIDIS: asymmetry modulated by azimuthal angle about virtual photon
    - BM contributes at twist-2, but Cahn effect also contributes at twist-4
    - HERMES and COMPASS have shown that the BM and Cahn contributions are comparable
  - Extra degree of freedom in dihadrons
    - Cahn effect impacts dihadron total momentum direction $P_h$
    - Utilize azimuthal angle about $P_h$, instead of the azimuth about the virtual photon
- **Advantages from a broader and higher $Q^2$ range at an EIC**
  - Broader $Q^2$ range probes evolution effects
  - Higher $Q^2$ suppresses Cahn effect in single-hadron asymmetries
  - Lower $Q^2$ for overlap with other SIDIS experiments

C. Dilks

# Dihadrons: Probing Spin-Orbit Correlations in Hadronization

Duke UNIVERSITY

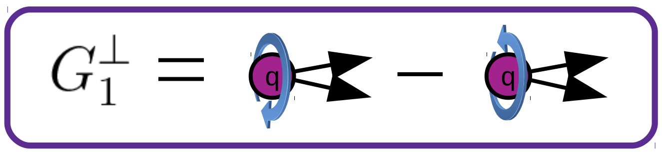
## Longitudinally polarized SIDIS:

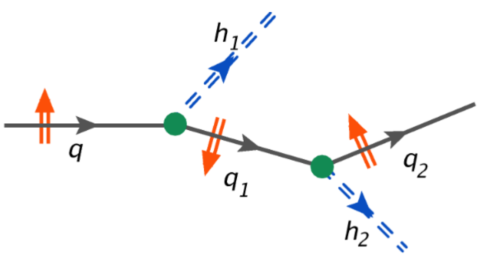
twist 2: { • $f_1(x)$ • $g_1(x)$ } ⊗ Helicity DiFF

twist 3: { • e(x) • $h_L(x)$ } ⊗ { • Collins DiFF • Interference FF }

### Helicity DiFF $G_1^{\perp}$:

- **Not yet constrained by data!**
- **Spin-orbit correlations** in hadronization
- Fragmenting quark acquires transverse polarization via ‘wormgear’ splitting in the quark-jet hadronization model
- Preliminary CLAS12 data indicate **significant effect**, dependent on invariant mass




### Collinear Twist-3 PDFs e(x) and $h_L(x)$:

- **CLAS6 data provided the first e(x) extraction, consistent with models; CLAS12 data appears to be in agreement**
- Moments of e(x) provide access to:
  - **Transverse color-force** on a transversely polarized struck-quark, in an unpolarized proton
  - **πN sigma terms:**
    - Quark mass contribution to proton mass
    - Quark chromomagnetic dipole moment → CP-odd!
- **No experimental constraints yet for $h_L(x)$**

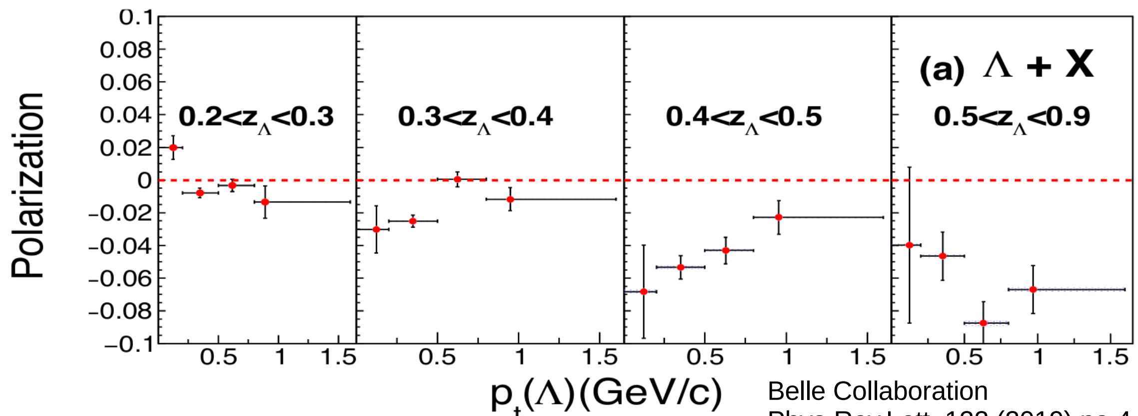
**EIC would expand kinematic coverage to a broader range, complementing and comparing to forthcoming JLab12 measurements**

## Transversely or Longitudinally polarized SIDIS:
Access several additional TMDs

C. Dilks

# Lambda Baryons

- Λ polarization is '**self-analyzing**': inferred by decay nucleon momentum
  - Access to **TMD-FF** with transversely polarized hadron $\mathbf{D_{1T}^{\perp}}$ as well as **transversity**
  - Could arise from **spin-orbit correlations** in fragmentation
  - Also access **quark polarization** in the collinear framework if Λ spin transfer is known
- **Significant nonzero polarization observed in $e^+e^-$, not yet measured in SIDIS**
- Observation of Λ polarization in SIDIS at JLab12 and an EIC give complementary access to $D_{1T}^{\perp}$
  - Flavor separation, Universality, and Evolution
  - Clean access to transversity
  - Acceptance in fixed-target SIDIS → challenging to measure Λ baryons
  - What detectors would we need at an EIC?




Belle Collaboration
Phys.Rev.Lett. 122 (2019) no.4, 042001

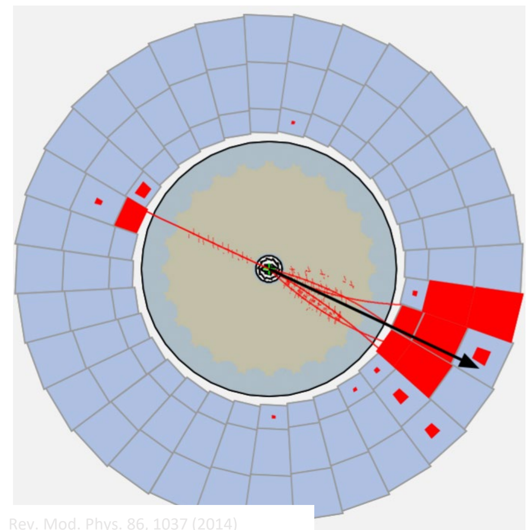
C. Dilks

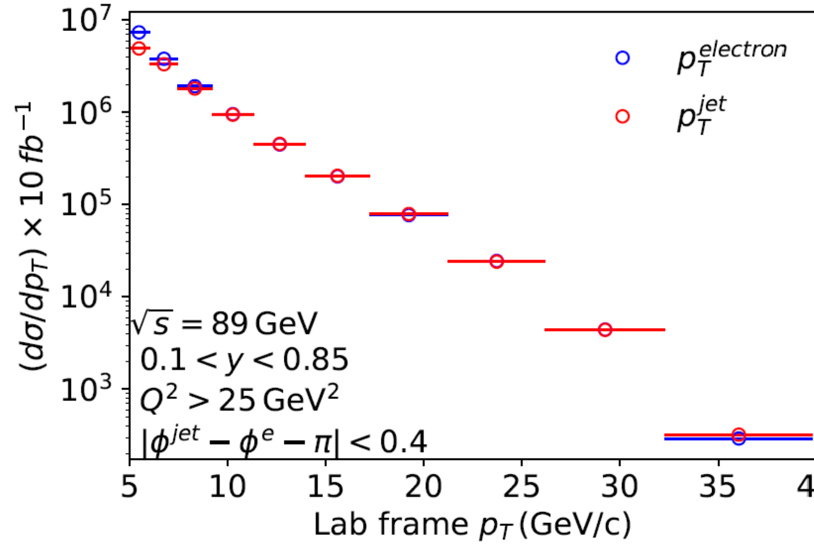
# Jets as Precision Probes in eA Collisions

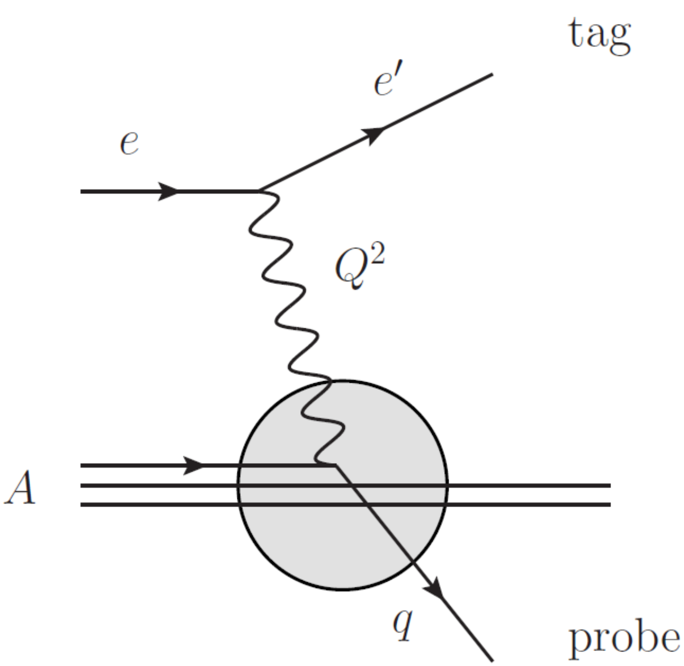
Miguel Arratia, U. of California Berkeley

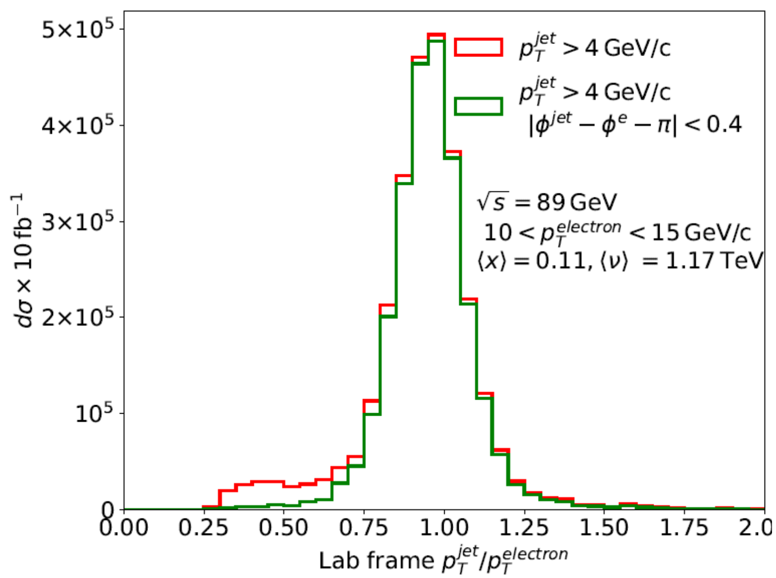
Jets as precision probes in e-A collisions *(later today on arXiv)*

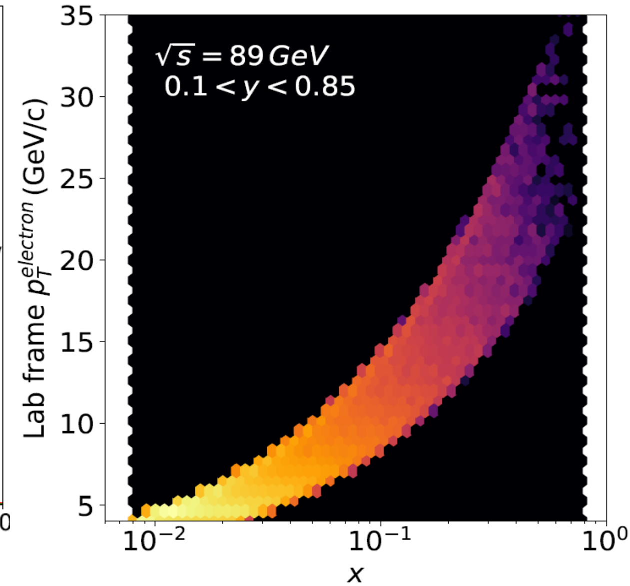
**Miguel Arratia, Youqi Song, Felix Ringer, and Barbara Jacak**
University of California, Berkeley



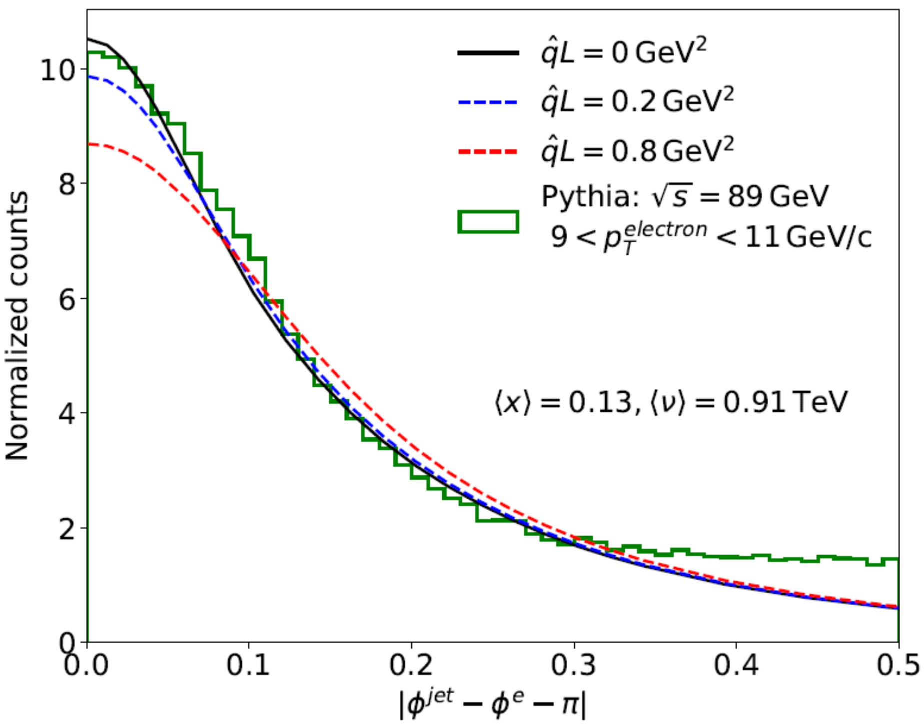



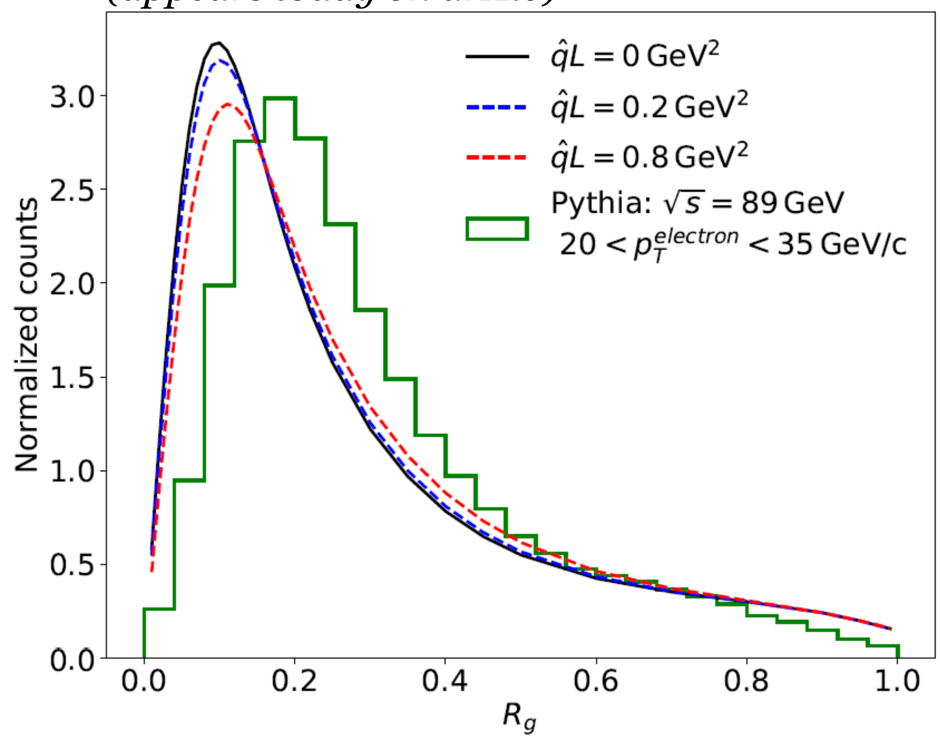



# Jet transport in nuclei

Traditional jet measurement
*PRL 122 192003 (2019)*




Jet substructure measurement
*(appears today on arXiv)*

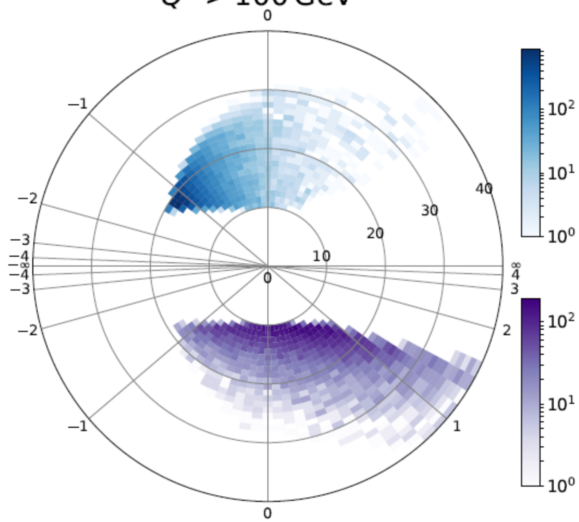



- Clean and orthogonal channels to measure jet transport parameter in e-A.
- Novel observables for TMD physics in e-p, not studied yet.

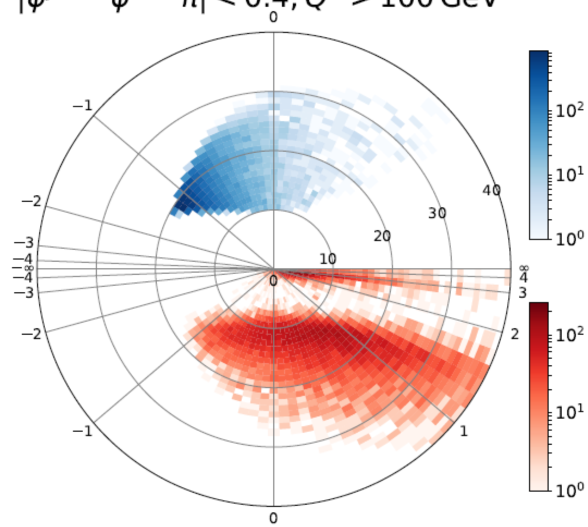
## Electrons Quarks Jets

High x, $Q^2$

$0.1 < y < 0.85, 10 < p_T^{electron} < 30$ GeV/c
$Q^2 > 100$ GeV$^2$

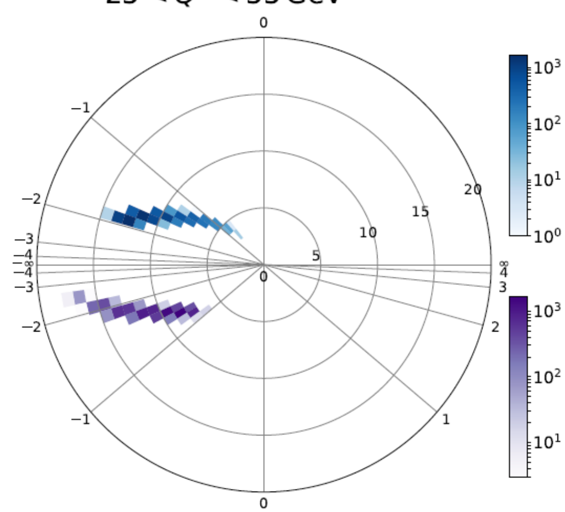


$0.1 < y < 0.85, 10 < p_T^{electron} < 30$ GeV/c
$|\phi^{jet} - \phi^e - \pi| < 0.4, Q^2 > 100$ GeV$^2$



Low x, $Q^2$

$0.1 < y < 0.85, 0.008 < x < 0.01$
$25 < Q^2 < 55$ GeV$^2$



$0.1 < y < 0.85, 0.008 < x < 0.01$
$|\phi^{jet} - \phi^e - \pi| < 0.4, 25 < Q^2 < 55$ GeV$^2$